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# THESIS

THE ECONOMIC CHOICE OF THE TRANSPORTATION ROUTES FOR LOGISTICS MATERIELS

by

Kim, Sook Han

March, 1991

Thesis Advisor: Richard E. Rosenthal

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Light Vehicle Battalions are used to transport logistic materiels from supply depots to combat units, on orders from high level logistics command. This thesis develops a linear programming model to determine which LVB should take which route, how much materiel it should take, and within what specific time it should travel to minimize transportation and storage costs. The linear programming model is derived from a peacetime scenario where each combat unit's demand varies seasonly. We report computational experience on a realistic problem using GAMS (the General Algebraic Modeling System).

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# THE ECONOMIC CHOICE OF THE TRANSPORTATION ROUTES FOR LOGISTICS MATERIELS

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# ABSTRACT

Light Vehicle Battalions are used to transport logistic materiels from supply depots to combat units, on orders from high level logistics command. This thesis develops a linear programming model to determine which LVB should take which route, how much materiel it should carry, and within what specific time it should travel to minimize transportation and storage costs. The linear programming model is derived from a peacetime scenario where each combat unit's demand varies seasonly. We report computational experience on a realistic problem using GAMS (the General Algebraic Modeling System).

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# I. INTRODUCTION

## A. INTRODUCTION AND MOTIVATION

Following orders from the Logistics Support Headquarters (LSHQ), the Light Vehicle Battalion (LVB) transports requested logistics materiels stored in supply depots to combat units. In order to provide the requested service, there are many possible routes available to the LVB. It is the duty of the LSHQ logistics staff officers to determine both the routes to be taken and the number of trucks to be used. Currently, the LSHQ's method of scheduling trucks and routes is based solely on past experience.

This thesis provides a linear programming model developed with GAMS (The General Algebraic Modeling System) [Ref. 1], as an aid to the Logistics Support Headquarters (LSHQ). The developed model is introduced to select the most economical transportation routes under various constraints.

## B. SCENARIO

The model developed in this thesis is demonstrated on a realistic problem derived from personal experience. Based on this experience, values are estimated for the amount of available logistics materiels stored at supply depots, the amount of logistics materiels requested by combat units, and the number of available LVB trucks. In addition to these quantities, we also estimate the storage cost for supply depots, intermediate supply points (ISPs), and combat units. All transportation and movement costs are derived from the field manual U.S. FM 101-10-1 [Ref. 4].

## C. PREVIOUS STUDIES

Two optimization approaches ([Ref. 7], [Ref. 9]) similar to this research have been performed. They are summarized in Table 1 where the contribution of this thesis is also demonstrated.

TABLE 1. SUMMARY OF PAST OPTIMIZATION APPROACHES

| | Korea | U.S. | This Thesis |
|---|---|---|---|
| Purpose | Decide economic emplacement of supply depot | Find the best location of ammunition distribution point | Find economic transportati -on routes |
| Scale | Battalion | Corps | Battalion |
| Condition | War | War | Peace |
| Important Constraints | Capability of battalions | Capability of points and reliability of each area | Transporting period and Road conditions |
| Data | Estimated | Estimated | Estimated |
| Tool | Fortran | GAMS | GAMS |
| Objective | Min distance | Max utility | Min cost |
| Year | 1988 | 1987 | 1990 |

## D. OUTLINE

This thesis presents a mathematical model which minimizes the LVB's cost of providing service. Chapter II more fully introduces the LVB transportation system. Chapter III presents our mathematical models and estimated data. Computational experience with the model is discussed in Chapter IV. Finally, conclusions are offered in Chapter V.

## II. LIGHT VEHICLE BATTALION (LVB) TRANSPORTATION SYSTEM

### A. COMMAND FLOW FROM LOGISTICS SUPPORT HEADQUARTERS TO LVB

#### 1. Combat Unit Request Procedure

In order to sustain combat readiness, combat units generally make yearly requests to Logistics Support Headquarters (LSHQ) for logistics materiels which are then allocated on a quarterly basis. The logistics requirements may change from time to time, sometimes even within the same year because of the introduction of a new weapon system, new tactics, or the occurrence of unexpected exercises or catastrophes. At the end of each quarter, unconsumed materiels are kept by the combat units. Storage facilities are readily available at a price.

#### 2. Logistics Support Headquarters Order Procedure

Logistics Support Headquarters (LSHQ) quarterly sends required logistics materiels, which are stored at supply depots, to various combat units using the Light Vehicle Battalions (LVBs). As previously stated, the LVB's delivery schedule is planned by the LSHQ logistics staff officer.

When developing the delivery schedule, the LSHQ logistics staff officer considers: the number of available vehicles in each LVB, the distance from each combat unit to each LVB, safety factors, and time. While restricted by these factors, the LSHQ logistics staff officer seeks to minimize storage and transportation costs.

The above procedure is summarized as a flow chart shown in Figure 1. [Ref. 6]

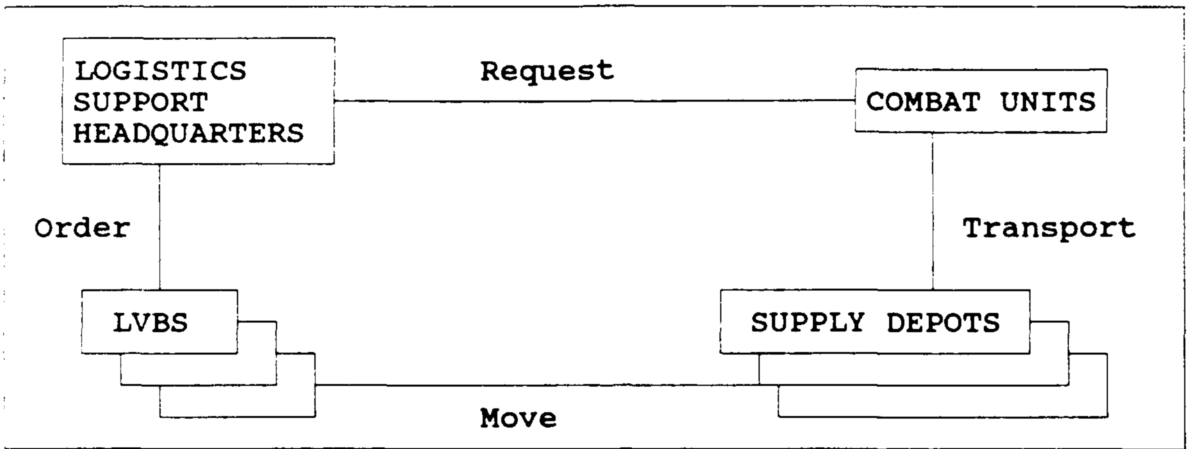


**Figure 1. Logistics Support Headquarter's order procedure.**

## B. ORGANIZATION OF LIGHT VEHICLE BATTALION

According to the LSHQ transportation plan, the LVB battalion headquarters has various LVCs (Light Vehicle Companies) under their control. Within battalion headquarters, there are three staff sections: the Operations section, the Manpower and Management section, and the Logistics section. The operations section is involved directly in transportation operations and training soldiers to drive and fight. The Manpower and Management section takes care of all transportation documents for the LVB. The Logistics section is responsible for the logistics materiels within the LVB. The LVB's organization is shown in Figure 2. [Ref. 6]

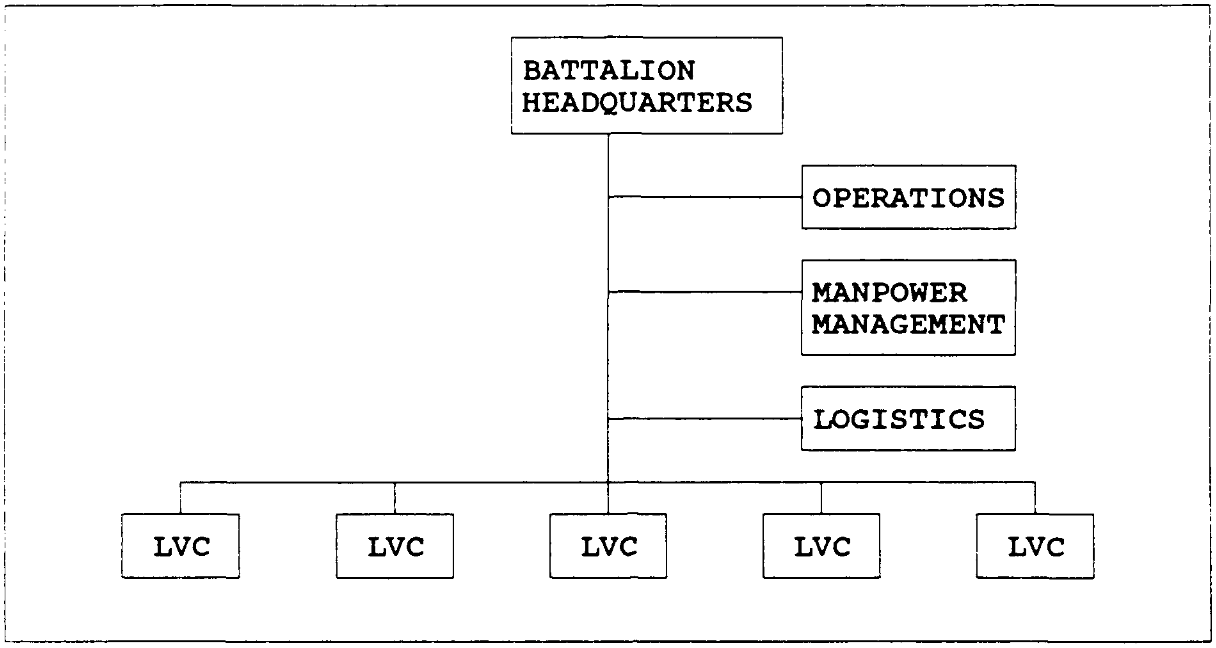


Figure 2. LVB Organization.

### C. COMMAND FLOW FROM THE LVB TO LVCs

According to LSHQ transportation requirements, the LVB schedules the LVCs. To obtain LVC schedule the LVB's operations staff officer considers the number of available vehicles, conditions of the vehicles, the workload, driver availability, and standing commitments. In practice, it is desirable to have workloads evenly distributed among various LVCs.

## D. TRANSPORTATION OF LVC

Every LVB transportation mission is performed by LVCs. After consulting the maintenance officer and platoon leader, the LVC commander determines whether or not he can perform the transportation mission and notifies the LVB operation's officer. If the commander undertakes a transportation mission, he orders the maintenance officer and platoon leader to prepare the number of vehicles predetermined by the LVB operations officer.

There are two kinds of transportation, i.e. direct and indirect. If the LVB transports materiels to combat units without using an intermediate supply point (ISP), this is called direct transportation. On the other hand, if the LVB uses an ISP, this is considered indirect transportation. When direct transportation is difficult, the LSHQ logistics staff officer could order the LVBs to transport materiels only to an ISP and then order the ISP to transport them to combat units. It is assumed that each ISP has sufficient storage and transportation capability for any mission.

In direct transportation, the LVC loads materiels at supply depots. Usually, the supply depots are located near the LVBs. In general, the supply depots have enough materiels to meet any combat unit requirements and they also have enough manpower to load materiels.

Supply depots get orders from LSHQ at the same time as the LVB. They therefore separately prepare for requested logistics. The flow chart of the relationship among LSHQ, LVBs, supply depots, ISPs, and combat units is shown in Figure 3. [Ref. 6]

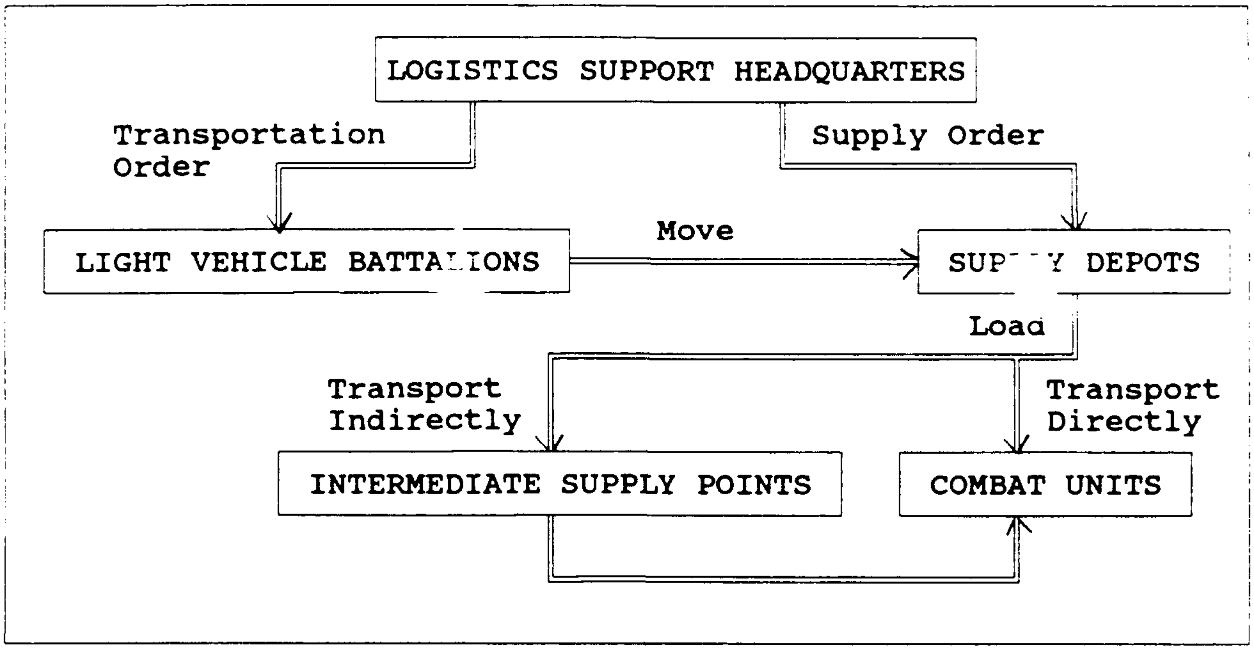


**Figure 3. Relationship among LSHQ, LVBs, supply depots, ISPs, and combat units.**

## E. DISCUSSION

### 1. Cost Minimization in Peace Time

It's desirable to meet combat units' requests as soon as possible, but resources (fuel, oil, trucks etc.) are limited. Especially in peace time, cost is an important consideration. To minimize cost, the LSHQ logistics staff officers have to select the appropriate LVB, the route to take, the amount of logistics materiels to order, and the appropriate time period.

### 2. Linear Programming (LP) Approach

Today, the approach taken by the logistics officer is based more on judgment and experience than on any scientific principle. Since this could easily provide suboptimal planning, a linear programming (LP) model is developed to aid the logistics officer's planning. The LP formulation considers combat units' demand, available supplies at supply depots, LVBs' transportation capabilities, storage capabilities at supply depots, ISPs, and combat units, and all possible routes among LVBs, ISPs, and combat units. GAMS, the General Algebraic Modeling System [Ref. 1], is adopted to implement this formulation.

# III. MODEL DEVELOPMENT AND FORMULATIONS

## A. SCENARIO

### 1. Specific Scenario

This is a description of the scenario for which the LP model has been developed. There are two LVBs, LVB1 and LVB2, in area ALPHA. They support three combat units COM1, COM2, and COM3, located in area BETA. There are also two ISPs, ISP1, and ISP2, between the LVBs and the combat units (Figure 4 exhibits this scenario). We allow the LVBs to transport materiels directly or indirectly. The planning horizon for our model is one year.

Because some routes may be closed due to heavy rain, snow, or frozen ground, logistics officers must be able to adjust their decision-making based on these variable factors. We therefore conduct a number of runs where certain routes are closed. This allows us to further demonstrate how our models can benefit the LSHQ logistics staff officer.

### 2. Data Assumptions

Based on past data, realistic amounts of available logistics materiels in each supply depot and the quantity requested from each combat unit was estimated. The transportation costs and the movement costs were determined using U.S. FM 101-10-1 [Ref. 4]. Combat units demand was given in 2.5-ton units, or equivalently the number of trucks. The cost of all logistics materiels was given in U.S. dollars. The amount of available logistics materiels in the three supply depots is listed in Table 2.1. The amount of logistics materiels requested from the three combat units is listed in Table 2.2.

LVBs incur movement costs when transporting empty vehicles to supply depots. The estimated cost of moving each LVB to each supply depot is shown in Table 3.1. We determined the cost as follows: The distance (in km) between each LVB and each supply depot is multiplied by 0.11 (gallons/km) to derive the amount of gas consumed. The result is then multiple 1.05 (dollars/gallon).

LVBs incur transportation costs when they transport requested logistics materiels to ISPs or combat units. The costs of transporting materiels from each supply depot to each ISP, from each supply depot to each combat unit, and from each ISP to each combat unit, are estimated in Tables 3.2.1, 3.2.2, and 3.2.3 respectively. The method used to calculate these values is as follows: The distance (in km) between locations is multiplied by 0.1305 (gallon/km) and then multiplied by 1.05 (dollar/gallon).

Each supply depot, ISP, and combat unit has its own storage space and associated storage costs. Estimated storage costs for supply depots are in Table 3.3. The storage costs for ISPs and combat units are derived by multiplying the supply depot's storage cost by 0.9 and 0.81, respectively. All storage costs are assumed to include the cost of building maintenance, managers, guards, and materiel losses. The fixed administration and guard costs are respectively determined as the number of administrators multiplied by 3 (dollars/person) and the number of guards multiplied by 2 (dollars/guard).

The cost of building maintenance and losses are allowed to vary from season to season. The costs of a materiel's loss or malfunction are estimated by summing the costs of the associated administrators plus the costs of building maintenance plus the costs of guards, multiplied by the materiel's loss rate.

The number of trucks available at each LVB in each period is listed in Table 4.

The result of this study depends on the numeric data used. This input can always be modified by potential users.

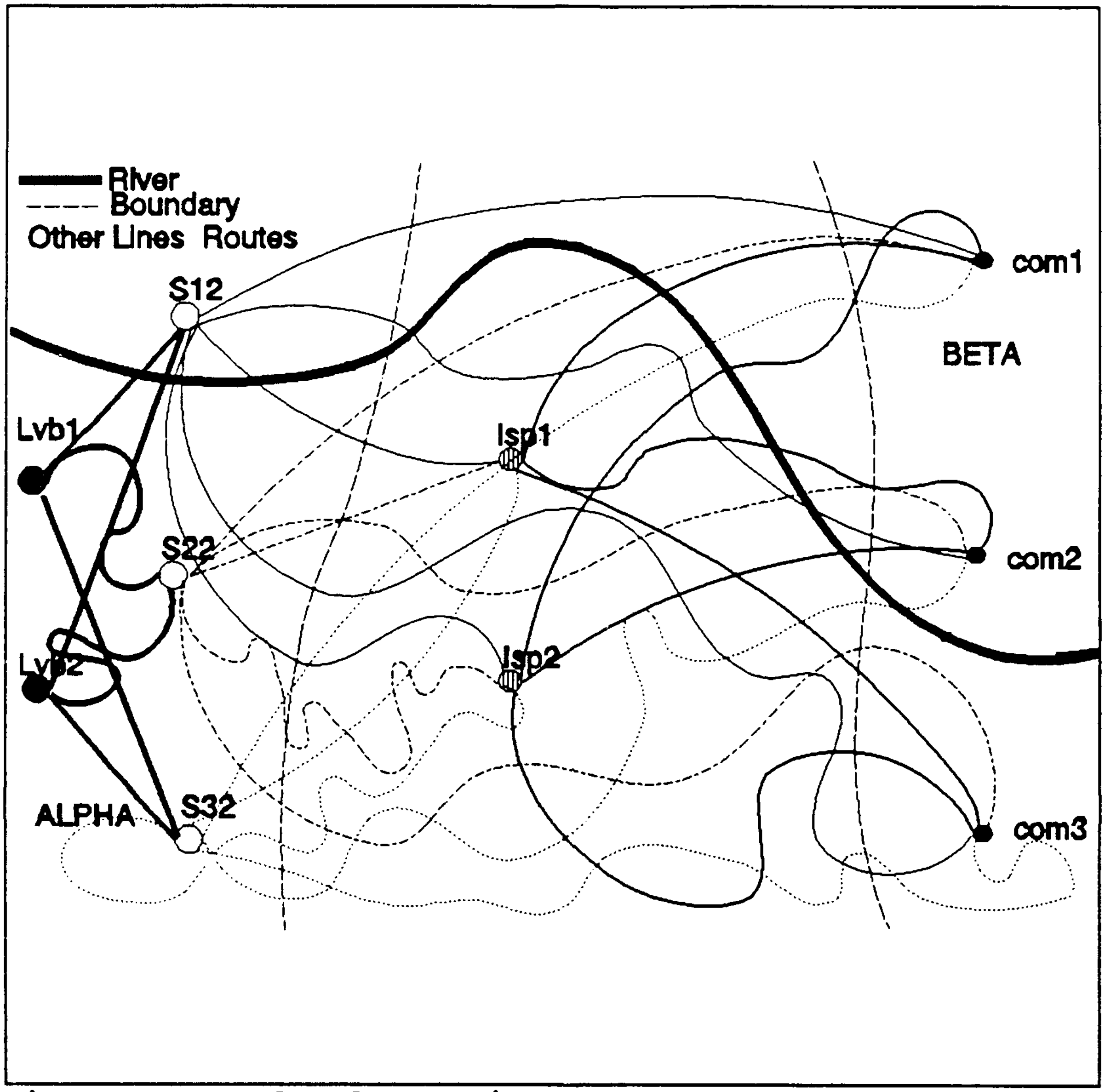

Figure 4. Developed scenario

[ **KEY** : **CEM** = **cement**, **AMM** = **ammunition**, **EX** = **exchange-items**,
**WP** = **weapon**, **MM** = **medical materiels**, **RP** = **repair-parts**,
**NP** = **non-military programs** ]

**TABLE 2.1. AVAILABLE LOGISTIC MATERIELS AT SUPPLY DEPOTS.**

| | SPRING | SUMMER | FALL | WINTER |
|---|---|---|---|---|
| S12 - FOOD | 22 | 33 | 25 | 39 |
| S12 - CLOTH | 27 | 44 | 57 | 28 |
| S12 - OIL | 22 | 29 | 13 | 75 |
| S12 - CEM | 22 | 33 | 25 | 39 |
| S12 - AMM | 27 | 44 | 57 | 28 |
| S12 - EX | 22 | 33 | 25 | 39 |
| S12 - WP | 27 | 44 | 57 | 28 |
| S12 - MM | 22 | 29 | 13 | 75 |
| S12 - RP | 22 | 33 | 25 | 39 |
| S12 - NP | 27 | 44 | 57 | 28 |
| S22 - FOOD | 83 | 44 | 25 | 37 |
| S22 - CLOTH | 52 | 13 | 24 | 65 |
| S22 - OIL | 32 | 42 | 31 | 16 |
| S22 - CEM | 83 | 44 | 25 | 37 |
| S22 - AMM | 52 | 13 | 24 | 65 |
| S22 - EX | 3 | 44 | 25 | 37 |
| S22 - WP | 52 | 13 | 24 | 65 |
| S22 - MM | 32 | 42 | 31 | 16 |
| S22 - RP | 83 | 44 | 25 | 37 |
| S22 - NP | 52 | 13 | 24 | 65 |
| S32 - FOOD | 32 | 23 | 15 | 15 |
| S32 - CLOTH | 43 | 72 | 91 | 34 |
| S32 - OIL | 50 | 63 | 52 | 87 |
| S32 - CEM | 32 | 23 | 15 | 15 |
| S32 - AMM | 43 | 72 | 91 | 34 |

| | | | | |
|---|---|---|---|---|
| S32 - EX | 32 | 23 | 15 | 15 |
| S32 - WP | 43 | 72 | 91 | 34 |
| S32 - MM | 50 | 63 | 52 | 87 |
| S32 - RP | 32 | 23 | 15 | 15 |
| S32 - NP | 43 | 72 | 91 | 34 |

**TABLE 2.2. COMBAT UNITS' LOGISTIC MATERIELS REQUEST.**

| | SPRING | SUMMER | FALL | WINTER |
|---|---|---|---|---|
| COM1 - FOOD | 10 | 20 | 25 | 20 |
| COM1 - CLOTH | 20 | 25 | 33 | 23 |
| COM1 - OIL | 22 | 13 | 10 | 25 |
| COM1 - CEM | 10 | 20 | 25 | 20 |
| COM1 - AMM | 20 | 25 | 33 | 23 |
| COM1 - EX | 10 | 20 | 25 | 20 |
| COM1 - WP | 20 | 25 | 33 | 23 |
| COM1 - MM | 22 | 13 | 10 | 25 |
| COM1 - RP | 10 | 20 | 25 | 20 |
| COM1 - NP | 20 | 25 | 33 | 23 |
| COM2 - FOOD | 10 | 20 | 25 | 20 |
| COM2 - CLOTH | 20 | 25 | 33 | 23 |
| COM2 - OIL | 22 | 13 | 10 | 25 |
| COM2 - CEM | 10 | 20 | 25 | 20 |
| COM2 - AMM | 20 | 25 | 33 | 23 |
| COM2 - EX | 10 | 20 | 25 | 20 |
| COM2 - WP | 20 | 25 | 33 | 23 |
| COM2 - MM | 22 | 13 | 10 | 25 |
| COM2 - RP | 10 | 20 | 25 | 20 |
| COM2 - NP | 20 | 25 | 33 | 23 |
| COM3 - FOOD | 10 | 20 | 25 | 20 |
| COM3 - CLOTH | 20 | 25 | 33 | 23 |

| | | | | |
|---|---|---|---|---|
| COM3 - OIL | 22 | 13 | 10 | 25 |
| COM3 - CEM | 10 | 20 | 25 | 20 |
| COM3 - AMM | 20 | 25 | 33 | 23 |
| COM3 - EX | 10 | 20 | 25 | 20 |
| COM3 - WP | 20 | 25 | 33 | 23 |
| COM3 - MM | 22 | 13 | 10 | 25 |
| COM3 - RP | 10 | 20 | 25 | 20 |
| COM3 - NP | 20 | 25 | 33 | 23 |

[ Key : DIS = distance, GAL = gallon ]

**TABLE 3.1. MOVEMENT COST : LVBs TO SUPPLY DEPOTS.**

| | S12 | | | S22 | | | S32 | | |
|---|---|---|---|---|---|---|---|---|---|
| | DIS | GAL | COST | DIS | GAL | COST | DIS | GAL | COST |
| LVB1 | .5 | .055 | .058 | 1 | .110 | .116 | 0.75 | .098 | .100 |
| LVB2 | 1 | .110 | .116 | .5 | .055 | .058 | 0.75 | .098 | .100 |

**TABLE 3.2.1. TRANSPORTATION COST : SUPPLY DEPOTS TO ISPs.**

| | ISP1 | | | ISP2 | | |
|---|---|---|---|---|---|---|
| | DIS | GAL | COST | IS | GAL | COST |
| S12 | 17.5 | 2.28 | 2.39 | 35 | 4.57 | 4.80 |
| S22 | 16.5 | 2.15 | 2.26 | 40 | 5.22 | 5.48 |
| S32 | 14.5 | 1.89 | 1.98 | 43 | 5.61 | 5.89 |

**TABLE 3.2.2. TRANSPORTATION COST : SUPPLY DEPOTS TO COMBAT UNITS.**

| | COM1 | | | COM2 | | | COM3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | DIS | GAL | COST | DIS | GAL | COST | DIS | GAL | COST |
| S12 | 35 | 4.57 | 4.80 | 57 | 7.44 | 7.81 | 75 | 9.79 | 10.28 |
| S22 | 42 | 5.48 | 5.75 | 56 | 7.31 | 7.68 | 68 | 8.87 | 9.31 |
| S32 | 47 | 6.13 | 6.44 | 55 | 7.18 | 7.54 | [illegible] | 7.44 | 7.81 |

TABLE 3.2.3. TRANSPORTATION COST : ISPs TO COMBAT UNITS.

| | COM1 | | | COM2 | | | COM3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | DIS | GAL | COST | DIS | GAL | COST | DIS | GAL | COST |
| ISP1 | 17.5 | 2.28 | 2.39 | 35 | 4.56 | 4.79 | 50 | 6.52 | 6.85 |
| ISP2 | 32.5 | 4.24 | 4.45 | 20 | 2.61 | 2.74 | 25 | 3.26 | 3.26 |

[ KEY : SPR = spring, SUM = summer, WIN = winter,
MAINT = maintenance, TCOS = total cost ]

TABLE 3.3. STORAGE COSTS FOR SUPPLY DEPOTS.

| | | MANAGEMENT PERSONNEL | | BUILD ING-MAINT | GUARDS | | LOSS | | TCOS |
|---|---|---|---|---|---|---|---|---|---|
| | | # | $ | COST | # | $ | RATE | $ | $ |
| FOOD | SPR | 1 | 3 | 0.3 | 1.0 | 2 | 0.01 | 0.053 | 5.35 |
| | SUM | 2 | 6 | 0.4 | 1.0 | 2 | 0.02 | 0.168 | 8.57 |
| | FALL | 1 | 3 | 0.3 | 1.0 | 2 | 0.01 | 0.053 | 5.35 |
| | WIN | 2 | 6 | 0.5 | 1.0 | 2 | 0.02 | 0.170 | 8.67 |
| CLOTH | SPR | 1 | 3 | 0.3 | 1.0 | 2 | 0.01 | 0.053 | 5.35 |
| | SUM | 1 | 3 | 0.4 | 1.0 | 2 | 0.02 | 0.108 | 5.51 |
| | FALL | 1 | 3 | 0.3 | 1.0 | 2 | 0.01 | 0.053 | 5.35 |
| | WIN | 1 | 3 | 0.5 | 1.0 | 2 | 0.01 | 0.055 | 5.56 |
| OIL | SPR | 1 | 3 | 0.3 | 1.0 | 2 | 0.01 | 0.053 | 5.35 |
| | SUM | 2 | 6 | 0.4 | 1.0 | 2 | 0.01 | 0.084 | 8.48 |
| | FALL | 1 | 3 | 0.3 | 1.0 | 2 | 0.01 | 0.053 | 5.35 |
| | WIN | 2 | 6 | 0.5 | 1.0 | 2 | 0.01 | 0.085 | 8.59 |
| CEM | SPR | 1 | 3 | 0.2 | 1.0 | 2 | 0.01 | 0.052 | 5.25 |
| | SUM | 1 | 3 | 0.2 | 1.0 | 2 | 0.01 | 0.052 | 5.25 |
| | FALL | 1 | 3 | 0.2 | 1.0 | 2 | 0.01 | 0.052 | 5.25 |
| | WIN | 1 | 3 | 0.2 | 1.0 | 2 | 0.01 | 0.052 | 5.25 |
| AMM | SPR | 2 | 6 | 0.3 | 1.5 | 3 | 0.02 | 0.186 | 9.49 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SUM | 2 | 6 | 0.4 | 1.5 | 3 | 0.02 | 0.188 | 9.59 |
| | FALL | 2 | 6 | 0.3 | 1.5 | 3 | 0.02 | 0.186 | 9.49 |
| | WIN | 2 | 6 | 0.5 | 1.5 | 3 | 0.02 | 0.190 | 9.69 |
| EX | SPR | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.051 | 5.15 |
| | SUM | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.051 | 5.15 |
| | FALL | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.051 | 5.15 |
| | WIN | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.051 | 5.15 |
| WP | SPR | 2 | 6 | 0.3 | 1.5 | 3 | 0.03 | 0.279 | 9.58 |
| | SUM | 2 | 6 | 0.3 | 1.5 | 3 | 0.03 | 0.279 | 9.58 |
| | FALL | 2 | 6 | 0.3 | 1.5 | 3 | 0.03 | 0.279 | 9.58 |
| | WIN | 2 | 6 | 0.3 | 1.5 | 3 | 0.03 | 0.279 | 9.58 |
| MM | SPR | 1 | 3 | 0.2 | 1.0 | 2 | 0.02 | 0.104 | 5.30 |
| | SUM | 2 | 6 | 0.2 | 1.0 | 2 | 0.02 | 0.164 | 8.36 |
| | FALL | 1 | 3 | 0.2 | 1.0 | 2 | 0.02 | 0.104 | 5.30 |
| | WIN | 2 | 6 | 0.2 | 1.0 | 2 | 0.02 | 0.164 | 8.36 |
| RP | SPR | 1 | 3 | 0.1 | 1.0 | 2 | 0.02 | 0.102 | 5.20 |
| | SUM | 1 | 3 | 0.1 | 1.0 | 2 | 0.02 | 0.102 | 5.20 |
| | FALL | 1 | 3 | 0.1 | 1.0 | 2 | 0.02 | 0.102 | 5.20 |
| | WIN | 1 | 3 | 0.1 | 1.0 | 2 | 0.02 | 0.102 | 5.20 |
| NP | SPR | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.102 | 5.20 |
| | SUM | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.102 | 5.20 |
| | FALL | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.102 | 5.20 |
| | WIN | 1 | 3 | 0.1 | 1.0 | 2 | 0.01 | 0.102 | 5.20 |

**TABLE 4. NUMBER OF TRUCKS AVAILABLE AT LVBs.**

| | SPRING | SUMMER | FALL | WINTER | TOTAL |
|---|---|---|---|---|---|
| LVB1 | 500 | 500 | 500 | 500 | 2000 |
| LVB2 | 500 | 500 | 500 | 500 | 2000 |
| TOTAL | 1000 | 1000 | 1000 | 1000 | 4000 |

## B. FORMULATIONS

Two GAMS programs were developed and executed to address the points of this thesis. PROGRAM-1 determines the most economical LVB transportation routes. Specifically, the program minimizes overall costs during the specified time period. PROGRAM-2 determines the number of trucks needed by the LVBs to perform proper transportation operations during specific time periods. Each of these programs reflects a specific model (MODEL-1 and MODEL-2) of the given scenario.

### 1. FORMULATION FOR MODEL-1

#### a) INDICES

- i : Light Vehicle Battalion(LVB1, LVB2)
- j : Supply Depot(S12, S22, S23)
- k : Intermediate Supply Point(ISP1, ISP2)
- c : Combat unit(COM1,COM2,COM3)
- m : Logistic materiel(FOOD, CLOTH, OIL, CEM(cement), AMM(ammunition), EX(exchange-items), WP(weapon), MM(medical materiels), RP(repair-parts), NP(non-military programs))
- t : Period(SPRING, SUMMER, FALL, WINTER)

b) GIVEN DATA

$TAVAIL_{jmt}$ : available logistics materiel m at supply depot j in period t

$DEM_{cmt}$ : demand for logistics materiel m from combat unit c in period t

$SJCOST_{jmt}$ : storage cost of logistics materiel m at supply depot j in period t

$SKCOST_{kmt}$ : storage cost of logistics materiel m at ISP k in period t

$SCCOST_{cmt}$ : storage cost of logistics materiel m at combat unit c in period t

$MCOST_{ijt}$ : the cost of moving an empty truck from LVB i to supply depot j in period t

$TJKCOST_{jk}$ : the cost of transporting any materiel from supply depot j to ISP k

$TKCCOST_{kc}$ : the cost of transportation from ISP k to combat unit c

$TJCCOST_{jc}$ : the cost of transportation from supply depot j to combat unit c

$TRUCK_{it}$ : number of available trucks at LVB i in period t

c) **DECISION VARIABLES**

TSC : Total storage cost

TTC : Total transportation cost

TMC : Total movement cost

TC : Total cost

$JKTRANS_{jkmt}$ : amount of logistics materiel m transported from supply depot j to ISP k in period t

$JCTRANS_{jcmt}$ : amount of logistics materiel m transported from supply depot j to combat unit c in period t

$KCTRANS_{kcmt}$ : amount of logistics materiel m transported from ISP k to combat unit c in period t

$JSTORE_{jmt}$ : amount of logistics materiel m stored at supply depot j in period t

$KSTORE_{kmt}$ : amount of logistics materiel m stored at ISP k in period t

$CSTORE_{cmt}$ : amount of logistics materiel m stored at combat unit c in period t

$TRUCKUSE_{ijt}$ : number of trunks moved from LVB i to supply depot j in period t

d) **OBJECTIVE FUNCTION**

- **TOTAL COST** : The objective of the MODEL-1 study is to minimize the overall cost which consists of three components: storage cost(TSC), transportation cost(TTC), movement cost(TMC), TC (Total Cost) = TSC + TTC + TMC.

- **STORAGE COST** : There are three levels of storage, i.e. depot level, ISP level, and combat unit level. The total storage cost is the sum of keeping the materiels at each levels over all periods. Mathematically, the total storage cost is expressed as follows:

$$TSC = \sum_j \sum_m \sum_t J \times SJ + \sum_k \sum_m \sum_t K \times SK + \sum_c \sum_m \sum_t C \times SC$$

$J = JSTORE_{jmt}$, $K = KSTORE_{kmt}$, $C = CSTORE_{cmt}$,

$SJ = SJCOST_{jmt}$, $SK = SKCOST_{kmt}$, $SC = SCCOST_{cmt}$.

- **TRANSPORTATION COST** : There are three transportation costs which are incurred when travel is demanded from either supply depots to ISPs, supply depots to combat units or ISPs to combat units. The total transportation cost consists of these three cost components. Mathematically, the total transportation cost is expressed as follows:

$$TTC = \sum_j \sum_k \sum_m \sum_t JK \times JKC + \sum_j \sum_c \sum_m \sum_t JC \times JCC + \sum_k \sum_c \sum_m \sum_t KC \times KCC$$

$JK = JKTRANS_{jkmt}$, $JC = JCTRANS_{jcmt}$, $KC = KCTRANS_{kcmt}$

$JKC = TJKCOST_{jk}$, $JCC = TJCCOST_{jc}$, $KCC = TKCCOST_{kc}$

- **MOVEMENT COST** : Movement costs occur when empty trucks move from LVBs to supply depots. Taken over all periods, the total movement cost is expressed mathematically as follows:

$$TMC = \sum_i \sum_j \sum_t TRUCKUSE_{ijt} \times MCOST_{ijt}$$

e) **CONSTRAINTS**

- **AVAILABILITY** : The availability constraint specifies that the amount of materiels removed from a depot must not exceed what is available. Specifically, the amount of various materiels issued to ISPs and combat units have to be less than or equal to the sum of inventory at hand and the amount of available materiels at supply depots. Any supply depot excess is stored for the next period. Mathematically, the availability is expressed as follows:

$$-J_{-1} + \sum_k JK + \sum_c JC \leq TA + J \quad \forall \ j,m,t$$

$$J_{-1} = JSTORE_{jm,t-1}, \ TA = TAVAIL_{jmt}, \ J = JSTORE_{jmt}$$

- **DEMAND** : This constraint specifies that the amount of materiels needed by the combat units must be provided by a combination of stored and transported materiel. Any excess transported in period t is stored in period t+1. Mathematically, the demand is expressed as follows:

$$-C_{-1} + \sum_j JC + \sum_k KC \geq DEM + C \quad \forall \ c,m,t$$

$$C_{-1} = CSTORE_{cm,t-1}, \ DEM = DEM_{cmt}, \ C = CSTORE_{cmt}$$

- **BALANCE** : For ISP locations, the amount of materiel that enters must equal the amount of materiel that leaves and is stored. Mathematically, the balance is expressed as follows:

$$K_{-1} + \sum_{j} JK = \sum_{c} KC + K \quad \forall \ k, m, t$$

$$K_{-1} = KSTORE_{km,t-1}, \ K = KSTORE_{kmt}$$

- **TRUCK DEMAND** : The number of trucks used to transport from supply depots must equal the number of LVB trucks used. Mathematically, the truck demand is expressed as follows:

$$\sum_{k}\sum_{m} JK + \sum_{c}\sum_{m} JC = \sum_{i} TU \quad \forall \ j, t$$

$$TU = TRUCKUSE_{ijt}$$

- **TRUCK AVAILABILITY** : The number of LVB trucks moved to supply depots has to be less than or equal the number of trucks available. Mathematically, the truck availability is expressed as follows:

$$\sum_{j} TRUCKUSE_{ijt} \leq TRUCK_{it} \quad \forall \ i, t$$

f) **SUMMARIZED FORM**

MODEL-1's formulation is given below.

**MINIMIZE**

TC = TSC + TTC + TMC

**SUBJECT TO**

$$-J_{-1} + \sum_{k} JK + \sum_{c} JC \le TA + J \qquad \forall \; j,m,t$$

$$-C_{-1} + \sum_{j} JC + \sum_{k} KC \ge DEM + C \qquad \forall \; c,m,t$$

$$K_{-1} + \sum_{j} JK = \sum_{c} KC + K \qquad \forall \; k,m,t$$

$$\sum_{k}\sum_{m} JK + \sum_{c}\sum_{m} JC = \sum_{i} TU \qquad \forall \; j,t$$

$$\sum_{j} TRUCKUSE_{ijt} \le TRUCK_{it} \qquad \forall \; i,t$$

Where $J_{-1} = JSTORE_{jm,t-1}$, $TA = TAVAIL_{jmt}$, $J = JSTORE_{jmt}$

$C_{-1} = CSTORE_{cm,t-1}$, $DEM = DEM_{cmt}$, $C = CSTORE_{cmt}$

$K_{-1} = KSTORE_{km,t-1}$, $K = KSTORE_{kmt}$, $TU = TRUCKUSE_{ijt}$

## 2. FORMULATION FOR MODEL-2

### a) INDICES

i : LVB, j : Supply Depot, t : Period

### b) GIVEN DATA

$TAVAIL_{it}$ : number trucks available to LVB i in period t

$DEM_{jt}$ : supply depot j's demand for trucks in period t as determined by Model-1.

$MCOST_{ijt}$ : the cost of moving an empty truck from LVB i to supply depot j in period t

c) **DECISION VARIABLES**

TMC : total movement cost

$TRUCKUSE_{ijt}$ : number of truck moved from LVB i to supply depot j in period t

d) **OBJECTIVE FUNCTION**

- **MOVEMENT COST** : MODEL-2's objective is to minimize total movement cost. This cost is incurred whenever an empty truck is moved from LVBs to supply depots. Mathematically, the total movement cost is expressed as follows:

$$TMC = \sum_{i}\sum_{j}\sum_{t} TRUCKUSE_{ijt} \times MCOST_{ijt}$$

e) **CONSTRAINTS**

- **AVAILABILITY** : The number of LVB trucks moved to supply depots has to be less than or equal to the number available. Mathematically, the availability is expressed as follows:

$$\sum_{j} TRUCKUSE_{ijt} \leq TAVAIL_{it} \quad \forall \; i,t$$

- **DEMAND** : The number of LVB trucks moved to supply depots has to be greater than or equal to the number of trucks needed by supply depots. Mathematically, the demand is expressed as follows:

$$\sum_{i} TRUCKUSE_{ijt} \geq DEM_{jt} \quad \forall \; j,t$$

**f) SUMMARIZED FORM**

MODEL-2's formulation is given below.

**MINIMIZE**

$$TMC = \sum_{i}\sum_{j}\sum_{t} TRUCKUSE_{ijt} \times MCOST_{ijt}$$

**SUBJECT TO**

$$\sum_{j} TRUCKUSE_{ijt} \leq TAVAIL_{it} \quad \forall \; i,t$$

$$\sum_{i} TRUCKUSE_{ijt} \geq DEM_{jt} \quad \forall \; j,t$$

# V. COMPUTATIONAL EXPERIENCE AND ANALYSIS

## A. EXPLANATION OF RESULTS

We solve the described scenario as a linear program. It should be clear that such a solution is only a lower bound on the optimal solution. As the yearly demand is in truck units, the yearly truck movements are guaranteed integer. However, seasonal truck movements can be fractional. As any solution is only intended to provide a suggested schedule, the linear programming solution provides an excellent beginning, and in many cases, it also provides an integer solution. If an integer solution is absolutely required, GAMS/ZOOM can be used at increased computational effort.

MODEL-1 was implemented in GAMS. From the results of this implementation, one can determine the LVB's routes, as well as which materiels are supplied and stored at each location during each period. The output also specifies when LVB trucks should be moved to supply depots.

MODEL-2 determines the optimal number of LVB trucks which should be moved to supply depots. There are two reasons for using MODEL-2. The first reason is for verification of MODEL-1. As any run of the two programs, given the same data, should yield the same results. To provide this verification, the following data from MODEL-1 are duplicated in MODEL-2: the number of trucks available at each LVB in a specific period, the number of trucks needed at each supply depot in a specific period, and movement costs from each LVB to each supply depot. The optimal number of trucks, calculated by both MODEL-1 and MODEL-2, should be identical if the models are programmed correctly.

The second reason for using MODEL-2 is that one can easily calculate the optimal number of trucks which should be moved from each LVB to its respective supply depot. The LSHQ logistics officers should obtain economical movement routes and transportation routes to minimize costs, and should concern themselves with determining the necessary number of trucks needed at each LVB in a specific time period in order to perform proper transport allocations. If there is a lack of trucks because of mechanical malfunctions, poor maintenance, inspections, etc., logistics officers should immediately find a way to obtain the proper number of trucks to meet the demand of each LVB.

## B. RESULTS FROM MODEL-1

For the developed scenario, the optimal amount of logistics materiels to be transported from supply depots to ISPs or combat units is summarized in Table 5. Within this table, the quantities represent the total amount which includes all types of materiels, such as food, oil, and so on: The amount of logistics materiels to be transported from supply depots to ISPs or combat units is summarized. From this table, ISP1 is heavily used and S12 provides a relatively small amount of materiels. This relationship should clearly exist since transportation costs from supply depots to ISP1 are cheap and all costs from S12 are expensive. From an economic point of view, ISP2 and S12 should not be maintain due to under utilization. We should consider either relocating ISP2 and S12 or removing them completely.

**TABLE 5. AMOUNT OF MATERIEL TO TRANSPORT FROM SUPPLY DEPOTS TO ISPs AND COMBAT UNITS.**

| | | SPRING | SUMMER | FALL | WINTER | TOTAL |
|---|---|---|---|---|---|---|
| S12 | ISP1 | 0 | 0 | 94 | 0 | 94 |
| | ISP2 | 0 | 0 | 6 | 0 | 6 |
| | COM1 | 0 | 0 | 0 | 0 | 0 |
| | COM2 | 0 | 0 | 0 | 0 | 0 |
| | COM3 | 0 | 0 | 0 | 0 | 0 |
| S22 | ISP1 | 100 | 166 | 132 | 286 | 684 |
| | ISP2 | 0 | 0 | 0 | 0 | 0 |
| | COM1 | 0 | 0 | 0 | 0 | 0 |
| | COM2 | 0 | 0 | 0 | 0 | 0 |
| | COM3 | 0 | 0 | 0 | 0 | 0 |
| S32 | ISP1 | 228 | 252 | 272 | 158 | 910 |
| | ISP2 | 0 | 0 | 0 | 0 | 0 |
| | COM1 | 0 | 0 | 0 | 0 | 0 |
| | COM2 | 0 | 0 | 0 | 0 | 0 |
| | COM3 | 164 | 206 | 246 | 222 | 838 |
| TOTAL | | 492 | 624 | 750 | 666 | 2532 |

The total amount of logistics materiels to be transported from ISPs to combat units is summarized in

Table 6. From this table, we can see that COM1 and COM2 receive all their supply through ISP1. COM3 receive the bulk of its supply directly from supply depots and only very small amounts through ISP2.

**TABLE 6. AMOUNT OF MATERIEL TO TRANSPORT FROM ISPs TO COMBAT UNITS.**

| | | SPRING | SUMMER | FALL | WINTER | TOTAL |
|---|---|---|---|---|---|---|
| ISP1 | COM1 | 164 | 206 | 252 | 222 | 844 |
| | COM2 | 164 | 206 | 252 | 222 | 844 |
| | COM3 | 0 | 0 | 0 | 0 | 0 |
| ISP2 | COM1 | 0 | 0 | 0 | 0 | 0 |
| | COM2 | 0 | 0 | 0 | 0 | 0 |
| | COM3 | 0 | 0 | 6 | 0 | 6 |
| TOTAL | | 328 | 412 | 510 | 444 | 1688 |

Table 7 contains the amount of logistics materiels which should be stored at supply depots, ISPs, and combat units during specific time periods. Generally, the storage requirements of all supply depots, ISPs and combat units are very low. This is because storage cost is relatively high compare to transportation cost. In addition, it is assumed that the supply of materiels is executed very efficiently, i.e., there is no long supply delays.

TABLE 7. AMOUNT OF MATERIEL TO STORE.

| | SPRING | SUMMER | FALL | WINTER | TOTAL |
|---|---|---|---|---|---|
| S12 | 0 | 0 | 0 | 0 | 0 |
| S22 | 0 | 0 | 0 | 0 | 0 |
| S32 | 0 | 0 | 34 | 0 | 34 |
| ISP1 | 0 | 6 | 0 | 0 | 6 |
| ISP2 | 0 | 0 | 0 | 0 | 0 |
| COM1 | 0 | 0 | 0 | 0 | 0 |
| COM2 | 0 | 0 | 0 | 0 | 0 |
| COM3 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 0 | 6 | 34 | 0 | 40 |

Table 8 is the summary of total number of trucks required from each LVB to supply depots. These numbers are the same as the units of logistic materiels transported from supply depots to ISPs or combat units.

TABLE 8. NUMBER OF EMPTY TRUCKS TO MOVE FROM LVBs TO SUPPLY DEPOTS.

| | | SPRING | SUMMER | FALL | WINTER | TOTAL |
|---|---|---|---|---|---|---|
| LVB1 | S12 | 0 | 0 | 100 | 0 | 100 |
| | S22 | 0 | 0 | 0 | 0 | 0 |
| | S32 | 392 | 458 | 400 | 380 | 1630 |
| LVB2 | S12 | 0 | 0 | 0 | 0 | 0 |
| | S22 | 100 | 166 | 132 | 286 | 684 |
| | S32 | 0 | 0 | 118 | 0 | 118 |
| TOTAL | | 492 | 624 | 750 | 666 | 2532 |

## C. RESULTS FROM MODEL-2

MODEL-2 confirms the result of MODEL-1. The summary of result in Table 9 from MODEL-2 is the same as the result in Table 5 and Table 8 from MODEL-1.

**TABLE 9. UNITS OF LOGISTIC MATERIEL TO BE TRANSPORTED FROM SUPPLY DEPOTS TO ISPs AND COMBAT UNITS (which is the same as the number of truck that should move from LVBs to supply depots)**

| | SPRING | SUMMER | FALL | WINTER | TOTAL |
|---|---|---|---|---|---|
| S12 | 0 | 0 | 100 | 0 | 100 |
| S22 | 100 | 166 | 132 | 286 | 684 |
| S32 | 392 | 458 | 518 | 380 | 1748 |
| TOTAL | 492 | 624 | 750 | 666 | 2532 |

## D. SENSITIVITY ANALYSIS

### 1. Limited Access to Some Routes

Sometimes in the summer or winter, transportation routes may be closed because of heavy rain, snow, or frozen ground. When the LSHQ logistics officers decides the most economic transportation routes, they have to consider those seasonal limitations first. In MODEL-1 and MODEL-2, all routes are considered open for transportation. In what follows, we consider a number of scenarios where routes are closed. The results of these cases are summarized is Table 10 through 13.

In order to prevent trucks and supplies from being assigned by the models to those seasonally limited routes, each was assigned a cost ($1000) higher than any other route. From the result of this change, values of all variables shift. As is evident from this result, no transportation will now exist between blocked routes.

[Key: S--Supply depot, I--ISP, C--Combat Unit, TSJ--Quantity of stored materiels at supply depot, TSK--Quantity of stored materiels at ISP, TSC--Quantity of stored materiels at combat unit, $ -- cost]

TABLE 10. BLOCKAGE BETWEEN ROUTE S12 AND ISP1.

| | TRANSPORTATION AND STORAGE QUANTITY | | | | | $ | COMMENT |
|---|---|---|---|---|---|---|---|
| | SPR | SUM | FALL | WIN | TOTAL | | |
| S-I | 328 | 437.5 | 578.5 | 473 | 1817 | 16259.199 | No transportations |
| S-C | 164 | 206 | 152 | 193 | 715 | | |
| I-C | 328 | 412 | 604 | 473 | 1817 | | |
| TSJ | 0 | 4.5 | 10 | 0 | 14.5 | 196.33 | S12 - ISP1 |
| TSK | 0 | 25.5 | 0 | 0 | 25.5 | | |
| TSC | 0 | 0 | 0 | 0 | 0 | | |

TABLE 11. BLOCKAGE BETWEEN ROUTE ISP2 AND COM1.

| | TRANSPORTATION AND STORAGE QUANTITY | | | | | $ | COMMENT |
|---|---|---|---|---|---|---|---|
| | SPR | SUM | FALL | WIN | TOTAL | | |
| S-I | 328 | 437.5 | 514 | 464 | 1743.5 | 16258.758 | No transportations |
| S-C | 164 | 206 | 216.5 | 202 | 788.5 | | |
| I-C | 328 | 412 | 539.5 | 464 | 1743.5 | | |
| TSJ | 0 | 4.5 | 10 | 0 | 14.5 | 196.33 | ISP2 - COM1 |
| TSK | 0 | 25.5 | 0 | 0 | 25.5 | | |
| TSC | 0 | 0 | 0 | 0 | 0 | | |

TABLE 12. BLOCKAGE BETWEEN ROUTE S32 AND COM3

| | TRANSPORTATION AND STORAGE QUANTITY | | | | | $ | COMMENT |
|---|---|---|---|---|---|---|---|
| | SPR | SUM | FALL | WIN | TOTAL | | |
| S-I | 328 | 437.5 | 514 | 464 | 1743.5 | 16258.758 | No transportations |
| S-C | 164 | 206 | 216.5 | 202 | 788.5 | | |
| I-C | 328 | 412 | 539.5 | 464 | 1743.5 | | |
| TSJ | 0 | 4.5 | 10 | 0 | 14.5 | 196.33 | S32 - COM3 |
| TSK | 0 | 25.5 | 0 | 0 | 25.5 | | |
| TSC | 0 | 0 | 0 | 0 | 0 | | |

TABLE 13. BLOCKAGE OF TWO ROUTES: S12-ISP1 AND S32-COM3.

| | TRANSPORTATION AND STORAGE QUANTITY | | | | | $ | COMMENT |
|---|---|---|---|---|---|---|---|
| | SPR | SUM | FALL | WIN | TOTAL | | |
| S-I | 328 | 437.5 | 578.5 | 437 | 1817 | 16259.199 | No transportations |
| S-C | 164 | 206 | 152 | 193 | 715 | | |
| I-C | 328 | 412 | 604 | 437 | 1781 | | |
| TSJ | 0 | 4.5 | 10 | 0 | 14.5 | 196.33 | S12 - ISP1, S32 - COM3 |
| TSK | 0 | 25.5 | 0 | 0 | 25.5 | | |
| TSC | 0 | 0 | o | 0 | 0 | | |

From the above tables, it can be seen that the quantities of stored materiels and the storage costs are always the same for the different set of routes being blocked. However, the amount of transported materiels and the costs of transportation slightly varies.

## 2. Storage Cost Changes

The storage costs of supply depots, ISPs, and combat units are expected to vary. Let us assume that, in the case of food, cement, exchange-items, and repair-parts, storage costs for the fall at S32 are raised by one dollar, and the summer storage costs at ISP1 for cement, exchange-items, and repair-parts are also raised by one dollar. The results of these changes are summarized in Table 14.

TABLE.14. CHANGES IN STORAGE COSTS.

| | TRANSPORTATION AND STORAGE QUANTITY | | | | | $ | COMMENT |
|---|---|---|---|---|---|---|---|
| | SPR | SUM | FALL | WIN | TOTAL | | |
| S-I | 328 | 412 | 514 | 464 | 1718 | 16244.325 | No storage at ISP1 |
| S-C | 164 | 206 | 242 | 202 | 814 | | |
| I-C | 328 | 412 | 514 | 464 | 1718 | | |
| TSJ | 0 | 30 | 10 | 0 | 40 | 209.50 | |
| TSK | 0 | 0 | 0 | 0 | 0 | | |
| TSC | 0 | 0 | 0 | 0 | 0 | | |

From Table 14 above it can be seen that the quantities of materiels to be transported and to be stored at specific supply depots and ISPs vary from the values obtained from the blocked-route data discussed in Section D. 1. above. When the storage cost increased for some materiels mentioned above, the amount of storage at each depot is changed as well.

# V. CONCLUSIONS

Optimization efforts are applied to many issues in modern society. Especially in the military, optimizing the usage of limited resources is essential during peacetime. In this thesis the optimization approach is applied to military transportation operations. The focus is from the point of view of the logistics officers who control logistics materiels stored at supply depots, and vehicles within Light Vehicle Battalions (LVBs). These officers select the most economical transportation routes and the distribution of logistics materiels in order to minimize total costs.

Two models are developed for this research. The first model searches for the most economical transportation routes and the optimal amount of logistics materiels transported by LVBs using those routes; the other model calculates the number of vehicles needed by LVBs to perform the requested transportation orders effectively. In the case where access to some routes is limited, or some storage costs are changes, these factors are considered for analysis within the programs.

The approach of this thesis provides logistics officers a scientific and economical method of deciding which transportation routes to use, and the quantity of materiels to be carried by each route. The linear programming models developed in this thesis can be an effective aid to the logistics officer.

# LIST OF REFERENCES


1. Brooke, Anthony, Kendrick, David, and Meeraus, Alexander, GAMS: User's Guide, The Scientific Press, 1988.

2. Schrage, Linus, Linear, Integer and Quadratic Programming with LINDO, The Scientific Press, 1986.

3. Bazaraa, M. and Jarvis,J., Linear Programming and Network Flows, John Wiley and Sons, Inc., 1977.

4. U.S.Army, FM 101-10-1, Staff Officer's Field Manual Organizational, Technical, and Logistic Data, U.S.Army AG Publications Center, Baltimore, MD 21220, July 1976.

5. Transportation Reference Data, Headquarters Department of the Army, FM 55-15, June 1986.

6. Army Motor Transport Units and Operations, Headquarters, Department of the ROK Army, FM 55-30, March 1980.

7. Kang, J.S., The Research of Network Model for the Economic Emplacement of Supply Depot, Master's Thesis, Defense Postgraduate School, Seoul, Korea, December 1988.

8. Letter from LT. COL., Battalion Leader of the 70th Light Vehicle Battalion, Choon Chun, Kang Won Do, Korea, September 1990.

9. Mark J. Cain, A Gams-Based Model of the U.S.Army Wartime Ammunition Distribution System For the Corps Level, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1988.

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